

Effect of Steel Fibre on The Flexural Strength of Self-Compacting Concrete

Shivamkumar Upadhyay^{1*}, Aniket Patil², Gauri Desai³

Abstract

With the increase in demand in the construction industry Self-Compacting Concrete is becoming more popular due to its versatile nature of improved efficiency. But the SCC possesses some properties which makes it brittle under tensile forces. The behavior of SCC as a structural material can be improved with the addition of Steel Fibres in adequate amount. In fact, the fibre reinforcement mechanism can convert the brittle behavior of concrete into semi-ductile behavior of crack width that is acceptable under the structural design. Also, it improves the strength and ductility of the concrete member by improving the core confinement. The main objective of present work is, to study the influence of Steel Fibres on the workability and Flexure performance of SCC and to find the optimum percentage of steel fibre in the mix for better performance. The experimental investigation consists of M40 grade concrete. In this study fibre is added as 0.5%, 1%, 1.5% and 2% by the Volume fraction to study its influence on the fresh and hardened property of SCC. Various tests are conducted on concrete in its fresh and hardened state. The experimental investigation shows that with the increase in the fibre content the flexural strength of concrete also increases. The mix having 0.5%, 1% and 1.5% of fibres has adequate workability. In terms of compressive strength all mixtures satisfy the target compressive strength.

Keywords: Fiber reinforced self-compacting concrete, fiber reinforced concrete, self-compacting concrete

INTRODUCTION

With the increase in demand in the construction industry Self-Compacting Concrete (SCC) is becoming more popular due to its versatile nature of improved efficiency and working condition on construction sites. Implementation of SCC in construction work reduces labour-intensive work as it fills every corner of the formwork/shutter by its own weight and does not require any external or mechanical vibration. But the SCC also possesses some properties which makes it brittle under Tensile Forces. Available research work suggests that the behaviour of SCC as a structural material can be improved with the addition of the fibres in adequate amounts. (Aoude, Hosinie, Cook, & Mitchell, 2014) et. al.,

[1] presents the results from an experimental program that was conducted to study the axial behaviour of reinforced concrete columns constructed with SCC and SFRC. The use of steel fibres in columns transforms cover spalling from a sudden to a gradual mechanism, and reduces core crushing, but does not prevent bar buckling. The feasibility of producing fibre reinforced Self-Compacting Concrete (FRSCC) that can be cast into the place with minimum or no consolidation was investigated by (Khayat & Roussel, 2000) et. al., [2]. Highly flowable yet cohesive FRSCC capable of spreading into place without blockage can greatly facilitate construction ability of FRC. Such concrete with high slump flow of 650mm can develop compressive strength and

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Flexural toughness like those of conventional FRC that is vibrated into place high deformability was obtained when the fibre volume was limited to 0.5%. At 1% fibre, the filling ability was low but still considerably greater than that of conventional mix. (Ou, Tsai, Liu, & Chang, 2012) et. al [3]. conducted compressive test on cylinders were performed to characterize the compressive stress-strain behaviour of steel fibre reinforced [4]. concrete (SFRC) with a high reinforcing index. The results indicated that a higher reinforcing index was associated with a higher strain at peak stress and a higher toughness of SFRC. However, this improvement reached a limit at a fibre volume of approximately 2%. (Barros, Sena-Cruz, & Cunha, 2010) et. al., present the experimental result of both straight and hooked-end steel fibres pull-out tests on a self-compacting concrete medium are presented and discussed. The maximum pull-out load had an almost linear increase with the embedded length for both hooked end and straight fibres. However, this increase was more significant on the straight fibres, since the pull-out response of hooked-end fibres, regardless the fibre embedded length, is predominantly influenced by the mobilization and straightening of the fibre hooked-end. (Stahli, Custer, & Van Mier, 2008) et. al, [5]. attempted to use the flow properties of fresh self-compacting concrete to change the fibre distribution and orientation. Using a single mixture of fibre reinforced concrete containing 3% of 30mm long straight steel fibres, the fibre distribution and orientation was determined. Fibre segregation can lead to a much higher bending strength than expected due to fibre alignment only, at least if the segregated fibre is located along the tensile stressed part of fibre alignment and fibre distribution, which both can be influenced by the viscosity of the fresh concrete. (Ponikiewski, 2013) et. al.,^[6] The equation proposed to predict the deflection-CMOD relationship of SCC fits into the coefficient of variation of the formula for naturally vibrated concrete (NVC). However, the SCC achieves the maximum crack mouth displacement for lower deflections than NVC. (Liberato Ferrara, 2007) et.al.,^[7] applied the rheology of paste model to the mix design of fiber reinforced SCC. Fiber was included in the particle size distribution of the solid skeleton through the concept of an equivalent diameter, defined on the basis of the specific surface. The influence of fibers, type and quantity on the grading of the solid skeleton, minimum content and rheological properties of the paste required self-compactability and rheological stability were studied. (Aniket Patil, 2023) et.al.,^[8] prepared the cement sample containing varying dosage of SAP ranging from 0.1% to 0.5% by weight of cement. The samples were prepared by two methods, one contains only SAP in cement paste and other contains SAP and required amount of water for added dosage of SAP. It was observed that samples containing SAP along with extra water cured in air achieved higher compressive strength at 28th day. (Kalpak A. Zagade, 2021) et. al.,^[9] 3D analytical model of P+12 storied building have been generated for symmetric building models and analysed using structural analysis tool Etabs. Total 2 types of models are analysed and compared with response spectrum method the main parameter of the seismic analysis of structure are load carrying capacity, ductility, stiffness, damping and mass. (Manjunath V. Bhogone, 2021) et.al.,^[10] Studied the link between the fracture behavior of fiber reinforced concrete composite and underlying mechanism that influence the pullout behavior of fiber are studied. The influence of the fiber matrix bond on the cohesive stress response in fracture is evaluated for normal vibration compacted concrete (NC) and self-compacting concrete (SCC) matrixes. The fracture response of steel fiber reinforced SCC improves significantly when compared with steel fiber NC. The cohesive stress crack opening relationship derived from the measured fracture responses indicates that a significantly higher crack closing stress is generated at smaller crack opening if SFSCC than SFNC.

The addition of hooked-end steel fibres can result in an increase in flexural performance/strength by arresting the cracks at the time of crack widening. In fact, the fibre reinforcement mechanism can convert the brittle behaviour of concrete into Semi-Ductile behaviour of crack width that is acceptable under the structural design. Also, it improves the strength and ductility of concrete members by improving the core confinement. In this research work, steel fibre used is hooked at both end which provides excellent grip at the time of crack widening and avoids slippage of fibre which helps in arresting the crack in more efficient manner. With the addition of steel fibres, the concrete matrix does not lose its integrity and it does not react adversely with other constituents of concrete mix. Also, steel fibres have higher modulus of elasticity compared to the concrete which helps in better stress transfer. The main objective of present work is, to study the influence of Steel Fibres on the workability and flexural performance of Self compacting concrete and, to find the optimum percentage of Steel Fibres in mix for better performance [11-12].

MATERIAL AND METHODS

In this study the SCC of M40 grade was used. The mix design for self-compacting were developed in accordance with IS 415: 2000 and IS 10262: 2019. Concrete was prepared using ingredients like Portland Cement of 53 grade with 30% Fly Ash, fine aggregate (crushed/artificial sand) as per IS 383. In this Conplast SP 430 a super plasticizer is also used as an admixture, potable water is used for mixing of concrete. For a target mean strength of 40 Mpa, the water and powder content were 190Kg/m³ and 520Kg/m³, respectively. Table 1 shows the mass proportion for SCC. Cement with the fineness 283.7 and specific gravity 3.15 was used. The coarse and fine aggregate with specific gravity 2.74 and 2.62 respectively were used. The hooked end steel fibre was used. The aspect ratio of steel fibre was 60 (length: diameter = 30:0.5mm). The modulus of elasticity and tensile strength of steel fibre were equal to 210,000 N/mm² and 1100 N/mm² respectively. The hooked end steel fibres were added into the mix at various percentage such as 0.5% which corresponds to 39.2 kg/m³, 1% which corresponds to 78.5 kg/m³, 1.5% which corresponds to 117.75 kg/m³ and 2% which corresponds to 157 kg/m³ by the volume fraction.

Table 1. Mix Proportion for M40 grade SCC.

S. N.	Materials	Quantity
1	Cement	332 Kg/m ³
2	Fly Ash	143 Kg/m ³
3	Powder Content	520 Kg/m ³
4	Water	190 Kg/m ³
5	Fine Aggregate	568 Kg/m ³
6	Coarse Aggregate	1134 Kg/m ³

The concrete mix was prepared using on site drum concrete mixture. To measure the workability, segregate resistance and viscosity requirements of fresh concrete Flow Table, V-Funnel and L-Box test, were performed. To measure the compressive strength of the concrete with various percentage of steel fibre in the mix three cubes of 150mm size for every percentage of steel fibre for each testing period were casted using conventional steel moulds.

No vibration was used, the specimen was finished using light trowelling. The specimen was stored at the room temperature of 28 degree. The cube specimens were demoulded after 24 hours of casting. The curing was done using conventional tank curing method. The compressive strength test on cube specimen was conducted on 3-day, 7-day, 14-day, and 28-day from the date of casting for every percentage of fibre. The compression test on the cube specimen of size 150mm was performed in accordance with IS 516. During the test carried out on compression testing machine there was a constant rate of loading of 5.15 kN/sec over the concrete cube specimen. The average 28-day compressive strength of SCC obtained from standard cube was 43.31Mpa.

The flexure test on the beam specimen of size 150mm x 150mm x 700mm (width x depth x length) was carried out in accordance with IS 516. For flexure test, three beam specimen was casted for each percentage of fibre using wooden mould. No vibration was used, the specimen was finished using light trowelling. The specimen was stored at the room temperature of 28 degree. The beam specimen was demoulded after 24 hours of casting and the beam specimen were cured using tank curing method. As mentioned in IS 516, the dimension of the beam specimens was measured prior to the test. The specimen was then placed over the roller support of flexure testing machine at the span of 600mm centre to centre. During this test carried out on the flexure testing machine there was the constant rate of loading of 0.52 kN/Sec over the concrete beam specimen. After obtaining the maximum load applied the distance of crack formed from nearest support 'a' was measured. Then the flexural strength of the beam specimen was determined using formula mentioned in IS 516.

RESULT AND DISCUSSION

The results discussed below are mainly consist of the comparison between test results of the various test conducted on the conventional Self-Compacting Concrete (SCC) of M40 grade with the Fiber Reinforced Self-Compacting Fiber (FRSCC) of M40 grade containing different percentages of fiber in the mix in their fresh and hardened state. The test results of fresh and hardened concrete are tabulated and discussed below with the graph for better understanding. The tables consist of test results data of Flow table test, V-funnel test, L-Box test, Compressive strength, and Flexural strength. After tabulating the results, graphs were plotted to give a clear idea about the analysis. The discussion was made based on obtained results.

In the mentioned test result data, the specimen noted as PPC00 which represents the FRSCC mix containing 0% fiber in it that is the conventional mix of SCC used as reference to compare test results with the other mix of FRSCC containing different amount of fiber in it, the specimen noted as PPC05 represents the FRSCC mix containing 0.5% fiber by volumetric fraction which translates to 39.2 kg/m^3 in terms of weight, the specimen noted as PPC10 represents the FRSCC mix containing 1% fiber in it by volumetric fraction which translates to 78.5 kg/m^3 in terms of weight, the specimen noted as PPC15 represents the FRSCC mix containing 1.5% fiber in it by volumetric fraction which is equivalent to 117.75 kg/m^3 of weight of fiber and the specimen noted as PPC20 represents the FRSCC mix containing 2% fiber in it by volumetric fraction which translates to 157 kg/m^3 in terms of weight.

Flow Table Test

The test results obtained from the Flow Table Test conducted on the various concrete mix containing different percentage of fiber have been tabulated in Table 2. The following table shows the result in terms of the diameter of concrete spread in 'mm' under flow Table test.

Table 2. Result of Flow Table Test on SFRSCC.

Fibre percentage	Trial 1 (mm)	Trial 2 (mm)	Trial 3 (mm)	Avg (mm)
0%	760	750	750	755
0.5%	725	725	720	725
1%	700	705	695	700
1.5%	670	670	665	670
2%	620	620	615	620

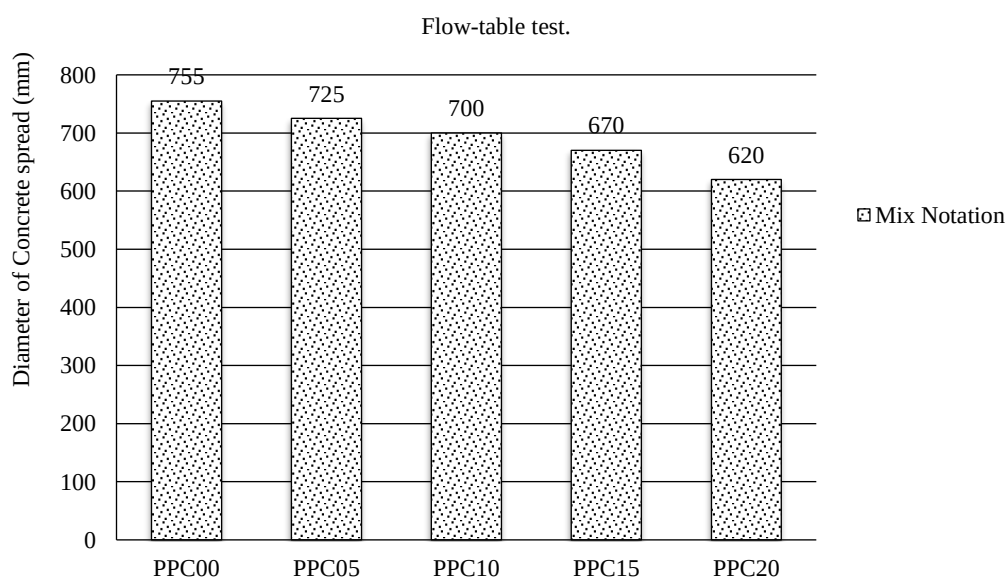


Figure 1. Average diameter of the FRSCC concrete flow in flow Table test.

Above mentioned results in table 2 and in Figure 1 shows that, for the concrete having 0% fibre in the mix, the diameter of the concrete spread was 755mm which satisfies the required slump flow class of the diameter of concrete spread suggested by Cl. 7.2.1, Pg. 10, IS 10262: 2019 under flow table test but when the fibre content in the concrete mix is increased by 0.5% then the diameter of the concrete spread reduced to 725mm which represent that the concrete mix having 0.5% fiber in it achieves up to 96% filling ability compared to that of the PPC00 mix. When the fibre content in the concrete mix is again increased by 0.5% to make it total 1% fiber content in the mix, the diameter of the concrete spread reduced to 700mm which represents that the concrete mix having 1% fiber content achieves up to 93% filling ability compared to that of the PPC00 mix and when the fibre content in the concrete mix is again increased by 0.5% to make it total 1.5% fiber content in the mix, then the diameter of the concrete spread significantly reduces to 670mm which represents that the concrete mix having 1.5% fiber in it achieves up to 87% filling ability compared to that of the PPC00 mix, which is still considerably acceptable but when the fibre content in the concrete mix is further increased by 0.5% to make it total 2% fiber content in the mix then the diameter of the concrete spread reduces to 620mm which significantly illustrate that the concrete mix having 2% fiber in it achieves up to 82.5% filling ability compared to that of the PPC00 concrete mix containing 0% fiber in it due to which the workability of this mix reduces significantly.

V-Funnel Tests

Results obtained from the V-Funnel Test conducted on the various concrete mix containing different percentage of fiber have been tabulated in Table 3. The following table shows the result in terms of time required by the FRSCC mix to flow out of the apparatus in terms of seconds under V-Funnel Test.

Table 3. Result of V-Funnel Test on SFRSCC.

S N.	SFRSCC fibre %	Seconds
1	0%	6.85
2	0.5%	7.32
3	1%	8.84
4	1.5%	11.53
5	2%	13.37

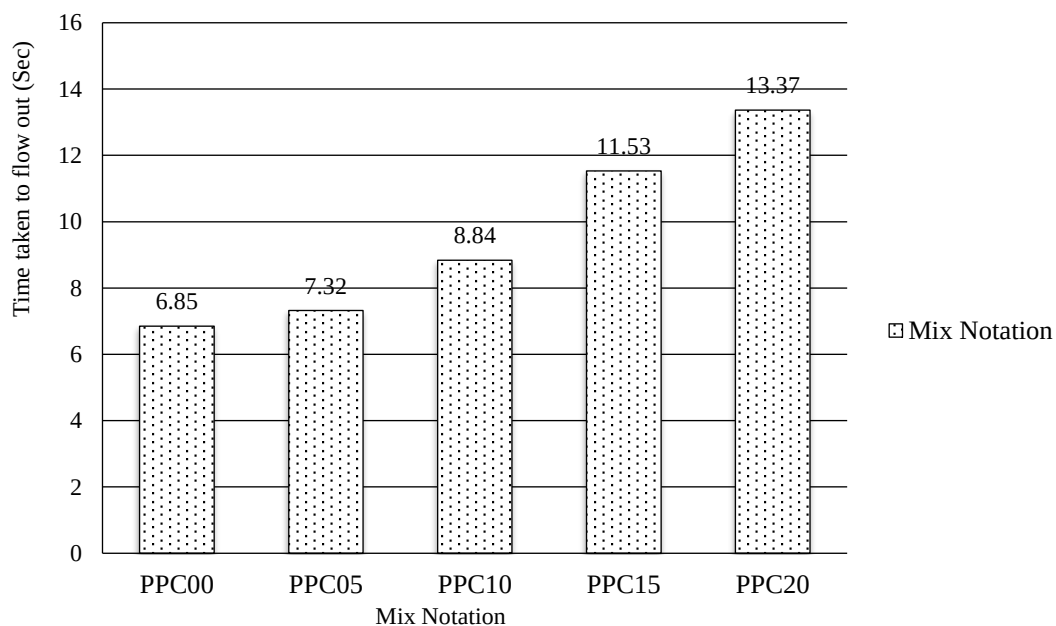


Figure 2. Time taken by FRSCC to flow out of the V-Funnel apparatus.

Above mentioned result in table 3 and figure 2 shows that, for the concrete having 0% fibre in the mix it requires 6.85 seconds to flow out from the V-Funnel apparatus which satisfies the required time suggested by Cl. 7.2.4, Pg 11, IS 10262: 2019 but when the fibre content in the concrete mix is increased by 0.5% then it takes 7.32 seconds to flow out from the apparatus which represents that the mix containing 0.5% fiber in it achieves viscosity up to 94% compared to that of PPC00 mix that contains 0% fiber in it. When the fibre content in the concrete mix is again increased by 0.5% to make it total 1% then the time required by it flow out from the V-funnel apparatus is 8.84 seconds which represents that the mix containing 1% fiber in it achieves viscosity up to 77.5% compared to that of PPC00 mix. Similarly, when the fibre content in the concrete mix is again increased by 0.5% to make it total 1.5% then it takes 11.53 seconds to flow out from the apparatus which represents that the mix containing 1.5% fiber in it achieves viscosity up to 60% compared to that of PPC00 mix but when the fibre content in the concrete mix is further increased by 0.5% to make it total 2% it takes 13.37 seconds to flow out from the apparatus which significantly illustrate that the mix containing 2% fiber in it achieves viscosity up to 51% compared to that of PPC00 mix that contains 0% due to which the filling ability of the mix that contains 2% fiber in it will reduce significantly.

L-Box Test

Results obtained from the L-Box Test conducted on the various concrete mix containing different percentage of fiber have been tabulated in Table 4. The following table shows the result in terms of ratio of height H2 by H1 of concrete passing through the L-Box.

Table 4. Result of Concrete Passing Ratio Under L-Box Test.

S.N.	% Fibre	H2/H1 (mm)	Ratio
1	PPC00	125/130	0.96
2	PPC05	125/132	0.94
3	PPC10	122/137	0.89
4	PPC15	119/140	0.85
5	PPC20	114/143	0.79

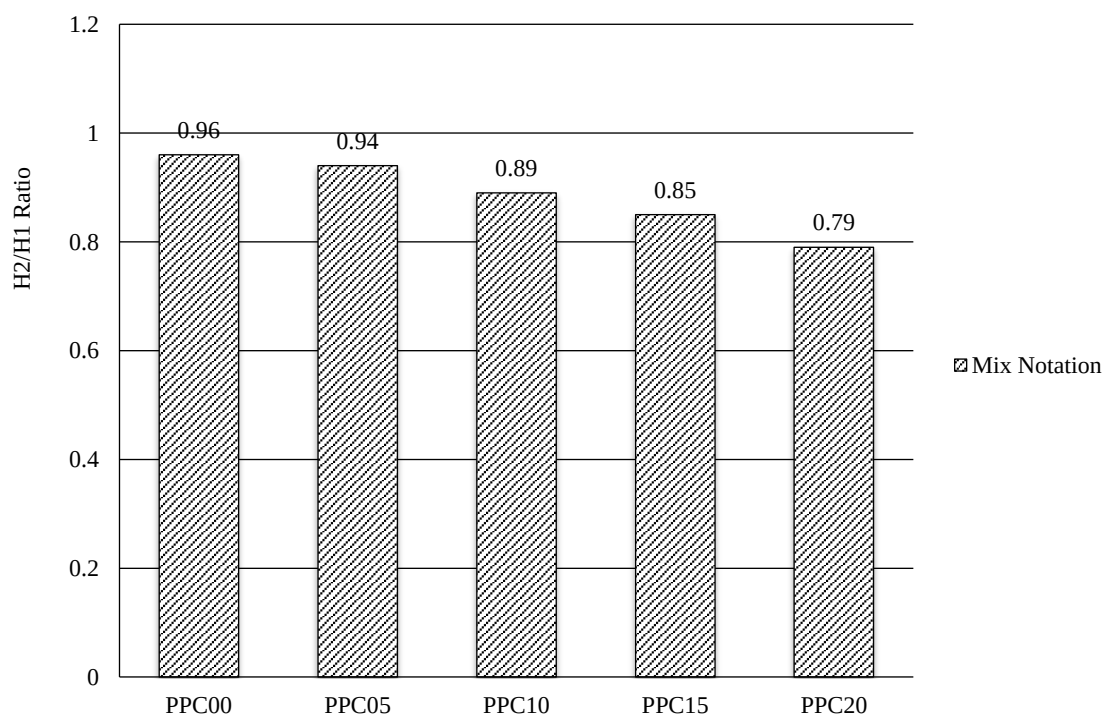


Figure 3. Concrete passing ratio of FRSCC in L-Box test.

Above mentioned result in table 04 and figure 03 shows that the concrete having 0% fibre in the mix have achieved the concrete passing ratio of 0.96 under L-Box test which satisfies the minimum passing ratio required for the mix as mentioned in the Cl. 7.2.2, Pg. 10, IS 10262: 2019 and when the fiber content in the concrete mix is increased by 0.5% hen it achieved the concrete passing ratio as 0.94 which represents that the concrete mix having 0.5% fiber content achieves 98% Passing Ability compared to the PPC00 mix which contains 0% fiber in it. When the fibre content in the concrete mix is again increased by 0.5% to make it total 1% content in the mix then this mix achieved the concrete passing ratio as 0.89 which represents that the concrete mix containing 1% fiber content achieves 93% passing ability compared to the PPC00 mix. Similarly, when the fibre content in the concrete mix is again increased by 0.5% to make it total 1.5% fiber content then it achieved the concrete passing ratio as 0.85 which represents that the concrete mix having 1.5% fiber content achieves up to 89% passing ability compared to the PPC00 mix and when further the fibre content in the concrete mix is increased by 0.5% to make it total of 2% fiber content in the mix then it achieved the concrete passing ratio as 0.79 which significantly illustrate that the concrete mix having fiber content up to 2% achieves only 83% passing ability compared to that the PPC00 mix containing 0% fiber in it.

Compression Test

The results obtained from the compression test conducted on the cube specimen of 15cm size at the testing interval of 3-Days, 7-Days, 14-Days, and 28-Days containing various percentage of fiber have been tabulated in the table 5. Following table shows the average compressive strength of the cube specimen of various mix containing different percentages of fiber after 28 days of casting in 'N/mm²'.

Table 5. Result of Compressive Strength of Cube of FRSCC.

Designation	3 Days		7 Days		14 Days		28 Days	
	N/mm ²	Avg.	N/mm ²	Avg.	N/mm ²	Avg.	N/mm ²	Avg.
PPC00	20.03	20.47	27.21	27.77	35.39	36.55	42.23	43.31
	20.43		26.50		36.73		42.85	
	20.94		29.60		37.52		44.84	
PPC05	19.21	19.67	28.10	28.38	35.56	35.19	41.88	42.15
	20.59		27.34		33.88		41.63	
	19.21		29.70		36.14		42.96	
PPC10	19.82	21.09	29.32	29.04	36.29	35.97	42.60	43.29
	21.67		29.79		34.72		42.85	
	21.79		28.01		36.90		44.40	
PPC15	21.16	21.81	30.68	31.11	37.79	37	43.30	44.01
	22.05		30.81		37.39		44.10	
	22.22		31.83		35.83		44.62	
PPC20	21.76	22.68	31.16	31.94	39.43	38.55	44.49	44.89
	22.90		32.05		37.58		44.89	
	23.39		32.59		38.65		45.29	

Results mentioned in the Table 5 represents the Compressive Strength value of cube specimens containing different percentages of fiber from being conventional SCC mix having 0% fiber content in it which is used as a reference mix for the comparison with other mix of FRSCC containing different amount of fiber up to 2% fiber content in it as 3-Days, 7-Days, 14-Days, and 28-Days as average compressive strength correspondingly. The results from the above-mentioned table are represented in the form of graph in Figure 4 for better understanding.

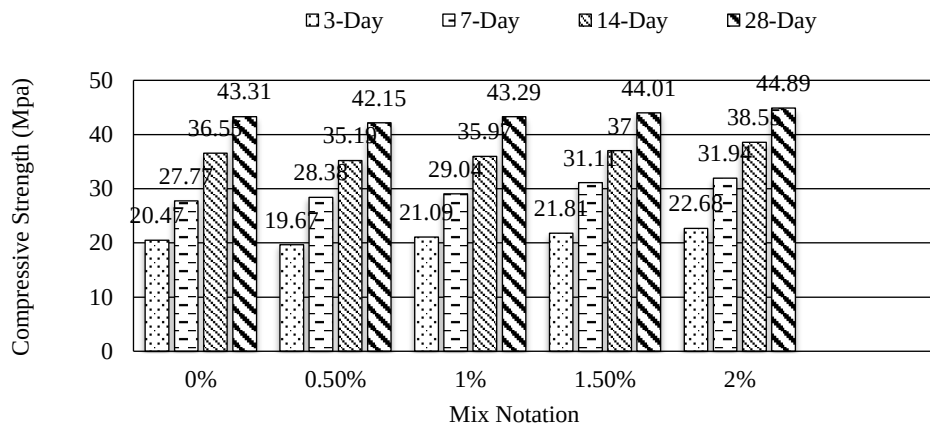


Figure 4. Average compressive strength after 28-Days.

Above mentioned table 05 and graph in figure 04 shows that the concrete mix having 0% fibre in it is having compressive strength of 43.31 N/mm² at 28-Days of testing which satisfies the target mean strength of the concrete and when the fibre content in the concrete mix is increased by 0.5% it shows the 28-Days compressive strength as 42.15 N/mm² which represents that the concrete mix having 0.5% fiber content in it achieves up to 97.35% relative compressive strength compared to that of the concrete mix PPC00 containing only 0% fiber in it. Following the test result mentioned in the table 5, it still satisfies the target mean strength for the same and when the fibre content in the mix is increased by 0.5% to make it total 1% fiber content, it shows the 28-Days compressive strength of 43.29 N/mm² which represents that the concrete mix having 1% fiber content in it achieves up to 100.05% of relative compressive strength compared to that of the mix containing only 0% fiber content in it which relatively similar to reference mix but when the fibre content in the concrete mix is again increased by 0.5% to make it total 1.5% fiber content in the mix it shows the 28-Days compressive strength as 44.01 N/mm² which illustrate that the concrete mix having 1.5% fiber content in it achieves up to 101.61% relative compressive strength compared to that of reference mix which is considerably higher than the reference mix and similarly when the fibre content in the concrete mix is again increased by 0.5% to make it total 2% it shows the average 28-Days compressive strength of 44.89 N/mm² which represents that the concrete mix having 2% fiber content in it achieves up to 103.46% relative compressive strength compared to that of the concrete mix containing only 0% fiber in it.

Flexure Test

The results obtained from the Flexure Test conducted on the beam specimen have been tabulated in Table 6. This table show the flexural strength of the beam specimen with various fibre contents tested after 28 days of casting.

Table 6. Result of Flexure Strength Test of FRSCC.

Designation	Flexure Strength (N/mm ²)			
	Beam 1	Beam 2	Beam 3	Avg
PPC00	4.54	4.523	4.535	4.536
PPC05	5.321	5.30	5.414	5.349
PPC10	5.957	5.885	5.797	5.88
PPC15	6.613	6.547	6.638	6.6
PPC20	7.424	7.488	7.345	7.42

Results mentioned in the Table 6 represents the average Flexural Strength value of beam specimens containing different percentages of fiber from being conventional SCC having 0% fiber content used as reference mix for the comparison with other mixes containing different amount of fiber to up to the SCC mix having 2% fiber content. The results from the above-mentioned table are represented in the form of graph in Figure 5 for better understanding.

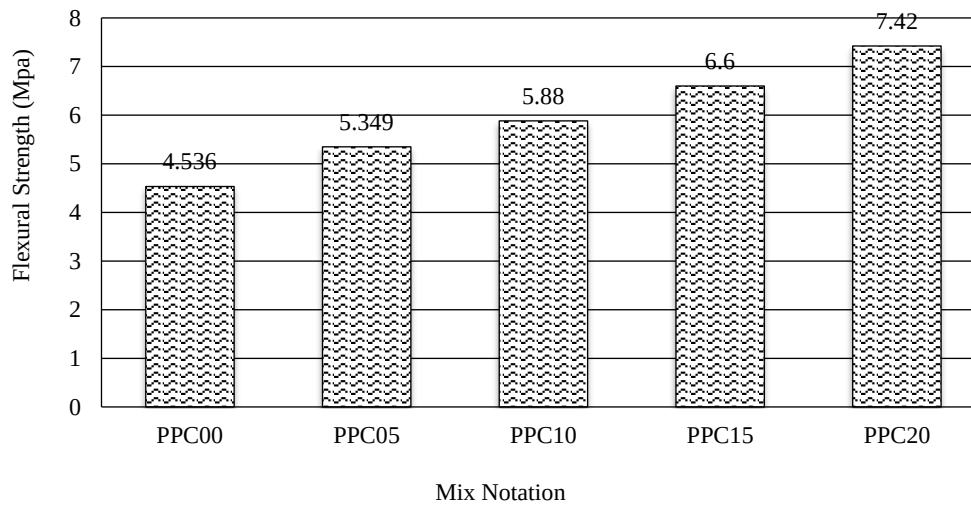


Figure 5. Average flexural strength after 28-Days.

Above mentioned result in table 06 and graph in figure 05 shows that the concrete mix having 0% fibre in it which is also a reference mix shows the average flexure strength of 4.536 N/mm² which satisfies the value of minimum flexural strength required for the concrete of M40 grade as 4.427 N/mm² (from the compressive strength of concrete) suggest as per the Cl. 6.2.2, Pg. 16, IS 456: 2000. When the fibre content in the concrete mix is increased by 0.5% then the beam specimen attains the average flexure strength of 5.349 N/mm² which represents that the concrete mix having 0.5% fiber content in it achieves up to 117.92% relative flexural strength compared to that of the concrete containing only 0% fiber in it which shows slight improvement in the flexural strength of the concrete with the inclusion of 0.5% fiber in it. When the fibre content in the concrete mix is increased by 0.5% to make it total 1% fiber content in it then the beam specimen attains the average flexure strength of 5.88 N/mm² which is relatively 129.62% higher than that of the concrete mix having 0% fiber in it, PPC00. And again when the fibre content in concrete mix is increased by 0.5% to make it total 1.5% fiber content then the beam specimen attains the average flexure strength of 6.6 N/mm² which represents that the concrete mix having 1.5% fiber content in it achieves the relative flexural strength up to 145.50% compared to that of the PPC00 mix having 0% fiber content in it which significantly illustrate that the concrete mix of PPC15 attains higher flexural strength compared to the reference mix. And further when the fibre content in the concrete mix is increased by 0.5% to make it total 2% fiber content then the beam specimen shows the average flexural strength of 7.42 N/mm² which represents that the concrete mix having 2% fiber content in it achieves the relative flexural strength up to 163.58% compared to that of the concrete mix having 0% fiber content in it, PPC00.

CONCLUSIONS

Based on the observed results and detailed analysis following conclusions are drawn from research investigation.

1. With the increase in the fiber content there is a significant increase in the Flexural Strength of the FRSCC.
2. As the fiber content in the mix of FRSCC increases, the Flow ability of FRSCC reduces.
3. As the fiber content in the mix of FRSCC increases, the time required for the FRSCC to flow out the V-funnel increases.
4. As the fiber content in the mix of FRSCC increases, the Concrete Passing ratio of FRSCC reduces.
5. There is not much change in the compressive strength of the concrete mix with various percentages of fiber in it.
6. The fiber content in the SFRSCC should be kept up to 1.5% by volume fraction to obtain the optimum flexural strength as well as workability of the concrete mix.

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